BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 07001

SUBJECT: Iodine Diffusion in the Skylab Potable Water Tanks - Case 620

DATE: July 2, 1970

FROM: J. J. Sakolosky

ABSTRACT

Iodine is used as a bactericide and injected into the Workshop potable water tanks during the Skylab mission. No mechanical provision exists for insuring that the iodine/water solution is thoroughly mixed after iodine injection. Furthermore, as is shown in this memorandum, molecular diffusion will not provide the mixing action required to obtain a uniform iodine concentration throughout each water tank.

An iodine injection scheme which causes a widespread initial distribution of iodine within each tank would help solve this problem. A more desirable alternative would allow the crew to manually stir the solution after iodine is injected. Several widely separated sampling ports would be useful in determining if a uniform iodine concentration has been reached.

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(NASA-CR-113372) IODINE DIFFUSION IN THE SKYLAB POTABLE WATER TANKS (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

Introduction

Potable water for the three Skylab missions is stored in 10 cylindrical tanks attached within the periphery of the Workshop. Each tank holds 665 lbs of water and is approximately 48 inches (1.2 meters) in length and 22 inches (.56 meter) in diameter. Water is expelled from the tanks by means of a bellows which is driven by high pressure oxygen.

Iodine is used as a bactericide for the Skylab potable water system. The tanks are launched with an initial concentration of iodine and monitored by periodic sampling; provision is made for the injection of a concentrated iodine solution into each tank when the residual concentration decreases below a pre-selected minimum. No provisions have been made to mechanically mix the iodine after it is injected. Vehicle attitude motion may provide some mixing, but, because the bellows within each tank prevents sloshing action, this effect might be negligible. In this memorandum, it is assumed that molecular diffusion is the only means of achieving a uniform distribution of iodine. The time required for complete diffusion is calculated.

Diffusion Model

The diffusion of molecules from a volume of high concentration to one of lower concentration is described by the three-dimensional diffusion equation given below.

$$\frac{\partial \rho}{\partial t} = D \left(\frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2} + \frac{\partial^2 \rho}{\partial z^2} \right)$$

ρ = concentration, gm/m^3

D = diffusion coefficient, m^2/day

x,y,z = distance, m

t = time, days

In the present analysis, the potable water tank will be approximated by a thin, finite cylinder which has the same length as the Skylab tank. This approximation reduces the problem to one dimension. The accuracy of the result will be sufficient to provide an estimate of the time required to reach a steady state condition following the injection of a concentrated iodine solution. The analysis assumes that the iodine is injected at one end of the tank.

A solution to the diffusion equation depends on the initial and boundary values of the problem. Many standard solutions exist in the literature, and often it is possible to merely look up a solution that fits one's own initial and boundary values. Unfortunately, most such solutions apply to infinite and semi-infinite media (e.g. an infinite or semi-infinite thin cylinder as opposed to the finite length cylinder of the present analysis); therefore, a ready solution was not on hand for the problem of interest here. But, in some cases, the solutions for infinite media can be extended to finite media by introducing the concept of reflections at a boundary. Thus, the solution for the infinite thin cylinder can be extended to the semi-infinite thin cylinder, and finally, to the finite length thin cylinder that is of interest. This procedure is carried out in the Appendix.

Results

A solution of the diffusion equation that satisfies the initial and boundary values of the present problem is given below.

$$\rho(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-x^2/4Dt} \left[1 + 2 \sum_{n=1}^{\infty} e^{-(Ln)^2/Dt} \cosh \frac{nxL}{Dt} \right]$$

ρ = concentration, gms/m^3

M = mass of iodine injected into tank, gms

A = cross-sectional area of cylinder, m^2

D = diffusion coefficient = .00005 m^2/day for iodine in water

t = time, days

x = distance along cylinder from iodine injection point, m

L = length of Skylab water tank = 1.2m

The above equation has been evaluated and resulting iodine concentration profiles are shown in Figure 1 for 50 days, 400 days, 1800 days, and 9000 days following injection of the concentrated iodine solution. The diffusion of iodine from an initial concentration at one end of the tank to a steady state uniform concentration is an extremely slow process in the Skylab water tanks. At x=L, approximately 9000 days are required for the concentration to reach 90% of its final value. At the end of eight months, corresponding to the end of the first three Skylab missions, iodine diffuses through only one third the length of the Skylab tank.

The method used to inject iodine into the tank could alleviate this problem somewhat. For example, a nozzle that sprayed the solution into the tank, or some other forceful means of achieving a large initial distribution of the concentrated solution is desirable. Even more desirable would be a manual provision that the crew could use to stir the solution in the tanks. For monitoring purposes, sampling ports at both ends of the tank would be helpful in determining if a uniform concentration of iodine has been reached.

MDAC-WD, the designers of the Workshop water storage system, are aware of the long diffusion time associated with iodine/water solutions.* They are currently considering the addition of a piston/cylinder mechanism that would enable the crew to manually mix the solution. Solution from the tank would be allowed to enter the cylinder and then, by means of the piston, would be forcefully injected back into the tank. The swirling action imparted to the solution would provide the desired mixing action. This system is still in the conceptual stage; its effectiveness must be demonstrated before serious consideration can be given to implementing it on the Skylab.

James J. Sakolosky

1022-JJS-cf J. J. Sakolosky

Attachments
  Figure 1
  Appendix

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*Personal Communication with T. Gallows, McDonnell-Douglas Astronautics Company - Western Division, June 12, 1970.

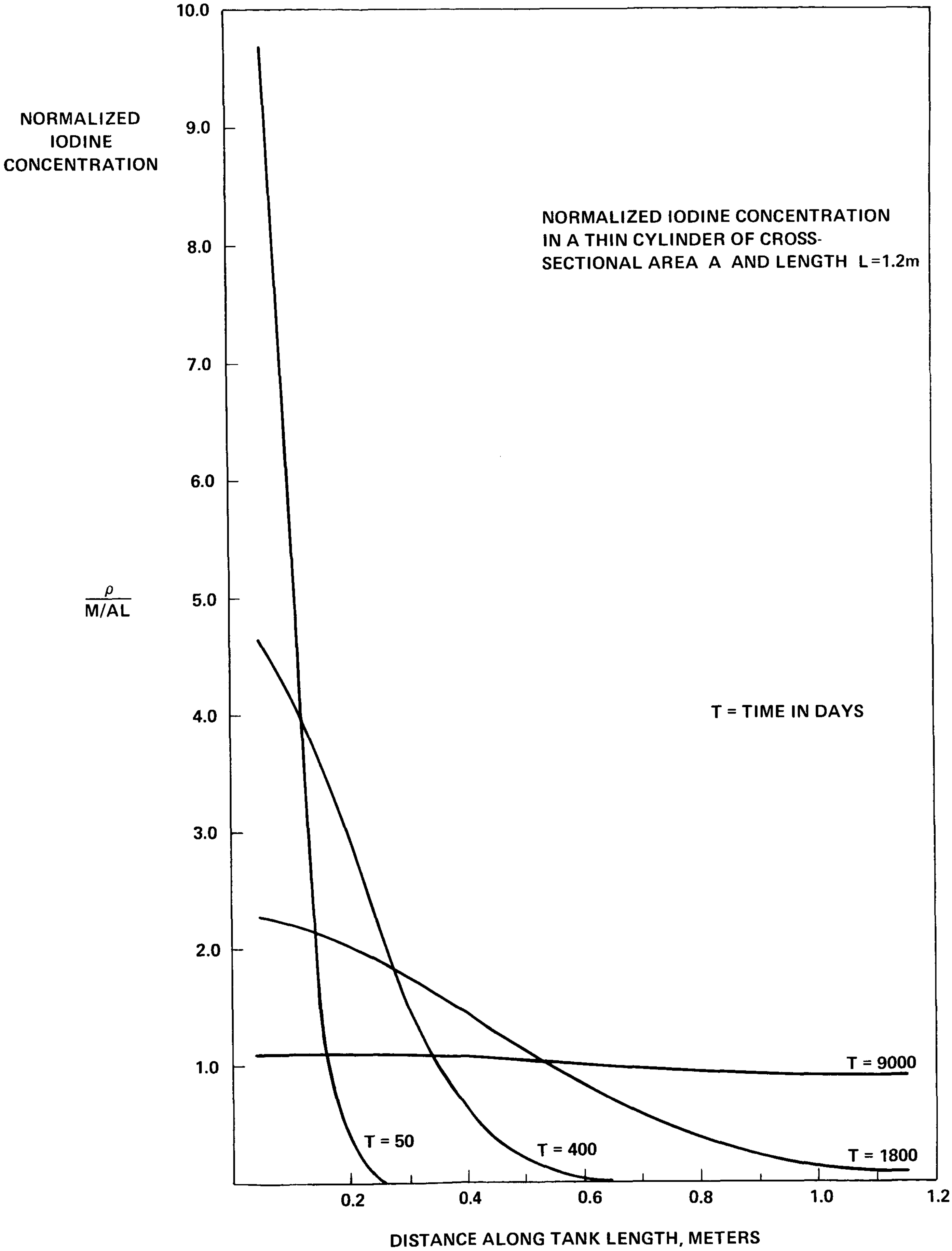

FIGURE 1 - NORMALIZED IODINE CONCENTRATION IN A THIN CYLINDER VERSUS TIME WHEN DIFFUSION IS THE ONLY MIXING FORCE ACTING

APPENDIX

The Skylab potable water tanks have been modeled as thin, finite cylinders of the same length as the actual tanks. This allows the three dimensional diffusion equation to be simplified to one dimension as given below.

$$\frac{\partial \rho}{\partial t} = D \frac{\partial^2 \rho}{\partial x^2}$$

The diffusion coefficient ($D = .00005\ m^2/day$)* is assumed to be constant for this analysis.

The concentrated iodine solution is injected into the cylinder at the plane x = 0; iodine concentration elsewhere throughout the cylinder is initially zero. Therefore, the initial iodine concentration profile for the problem is defined by a delta function:

$$\rho(x) = \frac{M}{A}\,\delta(x) \qquad \text{at } t = 0$$

M = mass of iodine injected into tank, gms

A = cross-sectional area of cylinder, m^2

The boundary values must satisfy the conditions imposed by zero flow across the ends of a finite cylinder of length L. Mathematically, the constraint may be represented as

$$\frac{\partial \rho(x,t)}{\partial x} = 0 \qquad \text{at } x = 0,\ x = L; \qquad \text{for all } t$$

Other conditions which must be satisfied are given below.

$$\frac{\partial \rho(x,\infty)}{\partial x} = 0 \qquad \text{for all } x$$

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*Handbook of Chemistry and Physics, Fortieth Edition, Chemical Rubber Publishing Company, Cleveland, Ohio, page 2170.

$$A\int_0^L \rho(x,t)\,dx = M, \qquad \text{all } t$$

These two conditions reduce to $\rho AL = M$ for large values of time. This form rearranged to

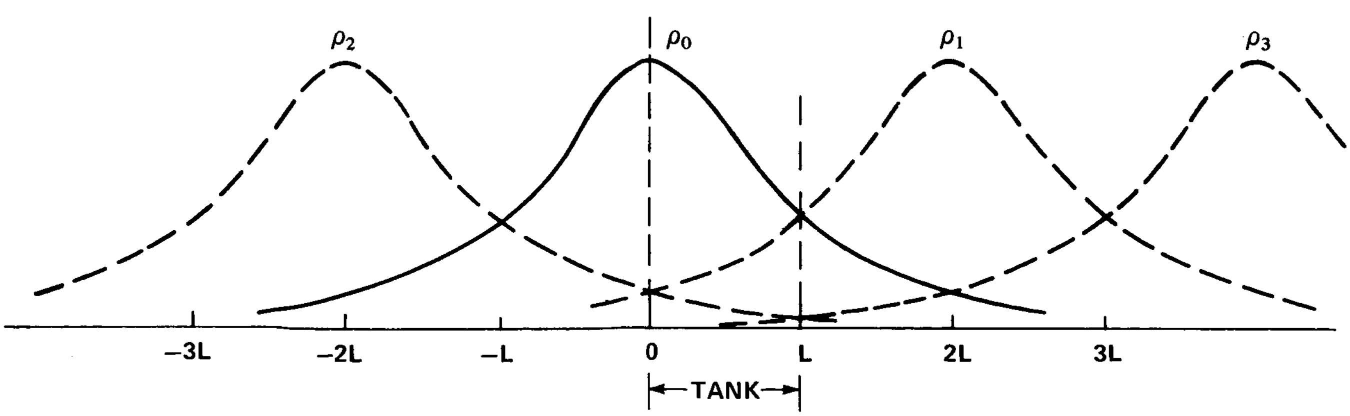
$$\frac{\rho(x,t)}{M/AL} = 1$$

will be used to check the solution for large values of time.

The solution to the one-dimensional diffusion equation for a semi-infinite, thin cylinder with an initial concentration of iodine in the plane of x = 0 is given in Reference A-1 as

$$\rho_0(x,t) = \frac{M}{A\sqrt{\pi Dt}}\, e^{-x^2/4Dt} \qquad (1)$$

This solution can be extended by the method of reflections (Reference A-2) to the finite cylinder used to model the Skylab tanks. The concentration distribution of equation (1) is assumed to be successively reflected at the boundaries x = L, x = 0, etc. The new solution is the superposition of the successive reflections on equation (1). Pictorially, this is shown below for some specific time during the process of diffusion.



Mathematically, the reflections at each boundary are described as follows.

<u>1st Reflection at x = L:</u>

$$\rho_1(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-(x-2L)^2/4Dt}$$

<u>1st Reflection at x = 0:</u>

$$\rho_2(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-(x+2L)^2/4Dt}$$

<u>2nd Reflection at x = L:</u>

$$\rho_3(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-(x-4L)^2/4Dt}$$

and so on ...

The final solution is given by

$$\rho = \rho_0 + \rho_1 + \rho_2 + \rho_3 + \ldots\ldots\ldots$$

After some manipulation this can be shown to be

$$\rho(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-x^2/4Dt} \left[1 + 2e^{-L^2/Dt}\left(\frac{e^{xL/Dt}+e^{-xL/Dt}}{2}\right) + 2e^{-(2L)^2/Dt}\left(\frac{e^{2xL/Dt}+e^{-2xL/Dt}}{2}\right) + 2e^{-(3L)^2/Dt}\left(\frac{e^{3xL/Dt}+e^{-3xL/Dt}}{2}\right) + \ldots\right]$$

Recognizing that

$$\frac{e^{u} + e^{-u}}{2} = \cosh u$$

the solution reduces to

$$\rho(x,t) = \frac{M}{A\sqrt{\pi Dt}} e^{-x^2/4Dt} \left[1 + 2 \sum_{n=1}^{\infty} e^{-(Ln)^2/Dt} \cosh \frac{nxL}{Dt} \right] \quad (2)$$

Checking the above equation against the boundary value condition

$$\frac{\partial \rho(x,t)}{\partial x} = 0 \quad \text{at } x = 0,\ x = L; \quad \text{all } t$$

one sees that the boundary values are satisfied. Figure 1 indicates that the condition

$$\frac{\rho(x,t)}{M/AL} = 1 \quad \text{as } t \to \infty$$

is also satisfied.

For the time range of interest, equation (2) can be approximated very well using only the first term of the infinite summation. When t equals 9000 days (the time at which the concentration at x = L reaches 90% of its final value), the ratio of the n = 1 term to the n = 2 term is 620 at x = L and 15,000 at x = 0. The ratio increases for shorter times.

REFERENCES FOR APPENDIX

A-1. Butkov, E., Mathematical Physics, Addison-Wesley Publishing Co., Palo Alto, California, 1968.

A-2. Crank, J., The Mathematics of Diffusion, Oxford University Press, London, England, 1956.

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Subject: Iodine Diffusion in the Skylab Potable Water Tanks

From: J. J. Sakolosky

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